Research Article

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Nutrient content and yield in relation to top breakover in onion developed from greenhouse-grown transplants†

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Abstract

BACKGROUND: Onions (*Allium cepa* L.) generally are harvested based on percentage of tops broken over. Since plant metabolism changes over time, percentage of tops broken over may be used to determine a harvest time to deliver marketable bulbs with the best nutrient content.

RESULTS: The cultivars Candy and Texas Grano 1015 Y were harvested at 10%, 20%, 30%, 40% and 50% breakover in 2006 and 2007. Larger and heavier bulbs were produced by Candy and in 2006, the year with near-normal precipitation. There was little difference in bulb size and weight due to percent breakover. Contents of chemical moieties in bulbs were affected by year, with the majority of values being higher in 2006, and there were either no differences due to cultivar, or where differences were found nitrate-N, phosphate and sulfate contents were lower in Candy. Soluble solids content was lower in 2006 and higher in Candy. Content of nitrogen and phosphorous in a Kjeldahl digest, nitrate-N, phosphate, potassium and sulfate were either linearly or quadratically distributed over percent breakover. Nitrite-N, calcium, magnesium, sodium and soluble solids were randomly distributed over percent breakover. Bulb size and weight did not change from the 20% breakover point, and most of the chemical moieties analyzed, with the exception of nitrate- and nitrite-N values, were highest below the 30% breakover.

CONCLUSION: Harvest occurring soon after breakover begins could be beneficial in terms of nutrient content without loss of bulb size or weight.

Keywords: *Allium cepa*; bulb; cultivar; development; size; weight

INTRODUCTION

The type of planting material used can affect yield of onion (*Allium cepa* L.).[1,2] Use of actively growing transplants produced in a greenhouse has been proposed for onion production.[2–5] When greenhouse-grown and bunched-plant bare-root transplants were used, the size of the bulb in plants developed from the planting materials did not greatly increase from 10% to the 50% top breakover stages for Walla Walla and Texas Grano 1015Y cultivars.[1,2] This indicates that it might be possible to harvest bulbs earlier without reducing numbers of bulbs in the larger classes. There appears to be a point at which keeping plants in the field for a longer period does not benefit bulb size, weight or yield.[1,2] An additional consideration is whether there are differences in nutrient content of bulbs at different top breakover stages.

There have been various interpretations regarding when onions should be harvested. Some consider that to maximize yield onions should be harvested when the percentage of tops broken over is: 0–20%;[6] 25–50%;[7,8] or 30–50%.[4] Others have suggested that for the fresh market[9–11] and dehydrator[12] onions should be harvested at 80% breakover to maximize fresh or dry weight. Onion top breakover, an indication of senescence, does not occur uniformly, either within sections of a field or over the entire crop. Russo[2] found that bulb diameter growth virtually ceases when the top breaks over. While all tops will eventually break over, there can be a period of days between the beginning of breakover and total breakover. Problems can occur during this time that may result in reduced quality. This has led to the concept of undercutting bulbs when convenient, which can stimulate maturation,[13] rather than

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harvesting when a specific amount of breakover has occurred.[14] The time between the beginning of top breakover and until most, or all, of the tops have broken over may affect nutrient content in bulbs. Using top breakover as a criterion for harvest at maximum bulb nutrient content has not been extensively examined.

Onion contains chemicals that are beneficial to humans.[15] How nutrients are sequestered in tissues is likely affected by factors affecting crop physiology. N, P and K contents in leaves of onion were affected by rate of N, P and K fertilizer rate; N fertilizer rate affected leaf tissue Ca and S content; and K fertilizer rate affected leaf tissue P content.[16] Nutrients, especially N, P and K in leaf tissue, are indicative of plant health, and are often used to determine whether additional fertilizer is required to support plant development.[17] Nutrient content in bulbs may be different from that in leaves. The cultivar Texas Grano 1015 Y, when harvested at 50% top breakover, had the lowest sucrose, glucose and total sugar contents, and the highest fructose and pungency, of several cultivars tested.[3] Russo[18] determined that there were no differences in contents of nutrients, or soluble solids, due to cultivar, plant density or nitrogen fertilization rate when bulbs were harvested at 50% breakover.

In order to determine when to harvest there is a need for clarification on whether nutritional content changes as onion plants mature. This project was undertaken to determine whether percent of top breakover can be used as a visible marker to determine nutrient content in bulbs of onion developed from transplants produced in a greenhouse.

MATERIALS AND METHODS

Experimental

Onion cultivars used were Texas Grano 1015 Y (short-day cultivar) and Candy (intermediate-day cultivar). Both cultivars can be grown in the southern United States, and Texas Grano 1015 Y, from transplants, although not specified for the southernmost states, seems to be adapted to the lower third of the United States as far as the border with Mexico.[19] Greenhouse-grown transplants were produced using the procedures of Russo.[2] Seeds were sown on 15 December 2006 and 14 December 2007 into a commercially available potting medium (Reddi-Earth, Scotts-Sierra Horticultural Products, Marysville, OH, USA) in 128-cell trays (Speedling®, Oklahoma Plant Products, Oklahoma City, OK, USA). The volume of each individual cell was 36 cm^3. Fertilization was begun about 2 weeks after sowing and continued weekly, with 1.5 g L^{-1} of Peter's soluble fertilizer (20 : 20:20; Spectrum Group, United Industries Corp., St Louis, MO, USA). Seedlings were maintained for 12 weeks. Irrigation was with overhead misters twice a day for 3 min per application. Transplant age used was based on the best estimation of yield from other research, where seedling ages ranged from 4 to 12 weeks.[4,5,9,20] Tops were trimmed to approximately 15 cm about 2 weeks before transplanting in both years and allowed to regrow. Transplanting was at the three- to four-leaf stage.

The experiment was conducted at Lane, OK, on a Bernow fine loamy, siliceous, thermic Glossic Paleudalf soil. Fertilizer was added in both years to bring soil residual fertilizer levels to 100N:112P:212K kg ha^{-1} in response to soil test results.[21]

Table 1. Precipitation and average maximum and minimum, and overall, average air temperatures and days to sampling for onion cultivars harvested through the various percentages of top breakover in each year. Dates in parentheses are the dates in each year at which the 10% breakover occurred. Other days to sampling are measured from the 10% breakover point

			Air temperature (°C)			
Percent breakover	Year	Total precipitation (cm)	Average maximum	Average minimum	Overall average	Days to sampling
Candy						
10	2006	33.2	24.3	11.9	17.9	97 (20 June)[b]
	2007	40.6	25.2	14.7	19.6	102 (22 June)
20	2006	33.2	25.5	12.3	18.3	99
	2007	–[a]	–	–	–	–
30	2006	33.3	25.5	12.8	17.9	100
	2007	41.8	25.7	16.1	20.6	109
40	2006	–	–	–	–	–
	2007	40.6	26.6	16.9	21.2	112
50	2006	33.3	25.8	13.0	18.7	103
	2007	41.8	26.4	17.3	21.5	113
Texas Grano 1015 Y						
10	2006	31.6	24.9	13.0	19.0	79 (2 June)
	2007	45.4	25.4	14.7	20.1	93 (13 June)
20	2006	32.9	26.2	14.0	19.9	86
	2007	50.4	26.3	15.9	21.1	102
30	2006	32.9	27.2	14.8	18.0	89
	2007	52.3	27.0	16.6	21.8	105
40	2006	32.9	28.0	15.2	19.0	90
	2007	–	–	–	–	–
50	2006	32.9	28.5	15.6	19.7	91
	2007	63.2	27.4	17.1	22.2	108

[a] '–', This percent breakover was not identifiable, maturation transitioned to the next percent breakover.
[b] Transplanting dates were 15 March 2006 and 12 March 2007.

Table 2. ANOVA table of effects of cultivar, percent of breakover, and year for plants with tops that were, or were not, broken over at the various harvest times on bulb diameter, and fresh and dry weights

		Weight (g)	
Source	Bulb diameter (mm)	Fresh	Dry
Year	**	**	**
Cultivar	**	**	**
Top condition	NS	*	NS
Percent breakover[a]	NS	*	NS
Year			
2006	93.9a[b]	411.5a	31.3a
2007	83.9b	322.0b	21.9b
Cultivar			
Candy	94.8a	428.5a	32.7a
Texas Grano 1015 Y	84.2b	316.9b	21.8b
Top condition			
Upright top	88.3a	356.1b	26.7a
Top broken over	90.1a	382.7a	27.1a
Percent breakover			
10	87.8a	345.7b	25.7a
20	89.2a	357.4ab	27.4a
30	88.9a	367.4ab	25.9a
40	90.2a	374.2ab	25.6a
50	90.4a	401.7a	29.4a

NS, non-significant; or significant at * $P \leq 0.05$ or ** $P \leq 0.01$ (ANOVA); there were no significant interactions.
[a] There were no linear, cubic or quadratic distributions.
[b] Values in a column followed by the same letter are not significantly different.
($P \leq 0.05$, Ryan–Einot–Gabriel–Welsch multiple *F*-test).

The source of N was ammonium nitrate (34 : 0:0), P was soluble triple superphosphate (0 : 46:0), and K was muriate of potash (0 : 0:60). The fertilizer was incorporated with a multifunction soil preparation implement (Do-All, Forrest City, AR, USA). Following disking, rough beds were formed with a hiller–furrower (Powell Manufacturing, Bennettsville, SC, USA). Finished beds on 1.9 m centers, formed with a tillovator and bed-shaper (Ferguson, Suffolk, VA, USA), were approximately 15 cm high and approximately 1.6 m across the top, and oriented north–south.

Transplants were moved to the field on 15 March 2006 and 12 March 2007 using a mechanical transplanter (Holland Co., Holland, MI, USA) and established in 100 m long beds. There were two rows per bed. Seedlings were planted approximately 15 cm in from the edges of the bed. Plant population corresponded to approximately 68 000 plants ha^{-1}. Guard rows were planted on the east and west of treatment rows. In 2007, the herbicide sethoxydim was applied 1 week after transplanting at 0.28 kg ha^{-1} of product. Approximately 1 month after transplanting in both years the herbicides oxyfluorfen and pendimethalin were applied at 0.06 and 1.12 kg ha^{-1} of product, respectively, over tops of plants. When needed, water was applied at the rate of approximately 5 cm per application by overhead irrigation. No insecticides or fungicides were applied.

Plants were monitored daily beginning before tops began to break over. Bulbs were planned to be harvested at 10%, 20%, 30%, 40% and 50% breakover. Beginning at 10% breakover, eight plants with broken-over tops, and eight visually comparable control plants with erect tops, were harvested. Tops were removed in the field about 5 cm above the bulb. Bulbs were transported to the laboratory. Bulbs were washed in tap water and dried. Fresh weights and diameters of four bulbs were determined. These bulbs were then cut into smaller pieces, placed in paper bags and then into a forced-air oven at 50 °C to dry until weights stabilized.

Chemical analyses

Four of the other bulbs were split in half. Tissue from one-half of the four split bulbs was used to determine soluble solids using a refractometer (PAL-1, Atago, Bellevue, WA, USA). The other halves of the bulbs were cut into smaller portions, placed in paper bags and then into a forced-air oven at 50 °C to dry until weights stabilized. Following drying tissues were ground with a hammer mill and passed through a 2 mm screen. In subsamples of tissues, levels of Ca, K, Mg, Na, nitrate-N, nitrite-N, phosphate (PO_4) and sulfate (SO_4) were determined in extracts using the methods of Russo and Karmakar[22] with a Lachat 8000 analytical system (Hach Co., Loveland, CO, USA) in the ion chromatography mode following methods provided by the manufacturer (anions with QuikChem method 10-510-00-1-A; cations with QuikChem method 10-520-00-1-B). Total nitrogen (TKN) and total phosphorus (TKP) levels in a Kjeldahl digest were determined in tissues in other subsamples with the same machine in the flow injection analysis mode using methods provided by the manufacturer (TKN with QuikChem method 13-107-06-2-D; TKP with QuikChem method 13-115-01-1-B).

Statistical analysis

A completely randomized design was used. Data for year (2), cultivar (2), breakover stage (5), top condition at sampling time (2; top broken over or not), and replication (3) were analyzed using the General Linear Methods procedures in SAS, version 8.1 (SAS Institute, Cary, NC, USA). Where interactions occurred they were used to explain results. If interactions did not exist, means were separated with the Ryan–Einot–Gabriel–Welsch multiple *F*-test, which is a conservative method used to separate means. Data relating to percentage of broken tops were subjected to linear regression analysis. Amounts of precipitation and minimum, maximum and average air temperatures were obtained from a State of Oklahoma statewide MesoNet® weather station located near the field where the experiment was conducted. Data were recorded at 15 min intervals.

RESULTS AND DISCUSSION

Precipitation was lower in 2006 than in 2007, and minimum, maximum and overall average temperatures were similar, or slightly lower, in 2006 than in 2007 (Table 1). Water to supplement precipitation was supplied twice in 2006, but irrigation was not necessary in 2007 (Table 1).

Plants of 'Candy' were exposed to lower average maximum and minimum, and overall average air temperatures in 2006 than in 2007 for samples taken at all breakover times. Plants of Texas Grano 1015 Y cultivar were generally exposed to lower average minimum and overall average temperatures in 2006 than in 2007, but average maximum temperature by the 30% and 50% breakover points were slightly higher in 2006 that in 2007. Texas Grano 1015 Y reached the last sampling time earlier than did Candy. For Texas Grano 1015 Y all sampling dates occurred more quickly than those for this cultivar as reported by Sargent *et al.*,[1] indicating that time to initiation and continuation of breakover are likely related to environmental conditions in specific production areas. In some instances differences in breakover percentages could not be clearly defined; i.e., for Candy in 2006 the amount of breakover went from 30% to 50% without a clear 40% delineation, and in 2007 the amount of breakover went from 10% to 30% without a clear 20% delineation; for Texas Grano 1015 Y in 2007 the amount of breakover went from 30% to 50% without a clear delineation at 40%.

Year and cultivar influenced bulb diameter and fresh and dry weights; top condition (broken over or not) and percentage of tops broken over affected fresh weights (Table 2). All sampled bulbs were within limits set for at least the 'large' category for fresh market onions.[23] Bulbs were larger, and fresh and dry weights heavier in 2006, and for Candy. Bulbs with broken-over tops were about 8% heavier than those with upright tops. Bulbs at 10% breakover were lighter than those at 50% breakover, and at all other times the weights were intermediate between extremes.

Year affected all but TKN and TKP content; cultivar affected nitrate-N, nitrite-N, PO4, Mg, Na and SO_4 content; cultivar affected nitrate-N, nitrite-N, PO_4, Mg, Na, SO_4 and soluble solids content; percent breakover affected all but nitrite-N, Ca, Mg and soluble solids contents (Table 3). Contents of TKN, nitrate-N, TKP, K, SO_4 and PO_4 were either linearly or quadratically distributed over breakover percentage, while the other chemical constituents were not. Top condition (broken over or not) did not affect nutrient content or soluble solids and there were no significant interactions. Levels of nitrate-N, nitrite-N, PO_4, K, Ca, Mg, Na and SO_4 were higher in 2006 than in 2007. Candy cultivar had higher levels of Mg and Na, and Texas Grano 1015 Y had higher levels of nitrate-N, PO_4 and SO_4. Values reported here for chemical moieties, and those for onion in the USDA Nutrition Database,[24] were near expected values in 2006, but generally lower in 2007. Generally warmer and wetter growing conditions may have affected deposition of nutrients in bulbs. Values in the USDA Nutrition Database represent averages, not ranges, of samples. Values in the database do not represent data from onions harvested at a specific breakover percent.

The distribution of chemical moieties that fit linear models could be classified by how they were distributed over breakover percentage (Fig. 1). Values for TKN and TKP could be described as being (although significantly) distributed within a relatively small range ($\mu g\ g^{-1}$), over breakover percentage. Others could be classified as decreasing as percent breakover increased (K, SO_4). Nitrate-N could be classified as increasing as percent breakover increased. Onion is classified as being very low in nitrate ($<200\ mg\ kg^{-1}$),[25] an observation that was confirmed in this instance. For nitrite humans consume about 44 $mg\ kg^{-1}$ of body weight per day, and there may be concerns with consumption levels above 40 $mg\ L^{-1}$.[26] This level was not reached even at the highest concentration found at 40% breakover.

The skips that occurred at breakover percentages in both cultivars complicated understanding of how interactions affected treatments since the missing information produced unbalanced datasets. However, main effects provided a degree of understanding of how sampling time explained results. Plants with and without tops broken over at all sampling times were similar in size and dry weight, and nutrient concentration in bulbs was not affected. This indicates that levels of nutrients in bulbs are not dependent on condition of the top.

Time to harvest may be affected by growing conditions, as was the case over the 2 years of this study. As a result the amount

Table 3. ANOVA table of effects of cultivar, percent of breakover, and year for plants with tops that were, and were not, broken over at the various harvest times on bulb nutrient content and content of soluble solids

	Nutrient ($\mu g\ g^{-1}$)										
Source	TKN[a]	Nitrate-N	Nitrite-N	TKP[a]	PO_4	K	Ca	Mg	Na	SO_4	Soluble solids (°Brix)
Year (Y)	NS	**	**	NS	**	**	**	**	**	**	**
Cultivar (C)	NS	**	**	NS	**	NS	NS	NS	**	**	**
Top condition (B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Percent breakover (*P*)	**	*	NS	**	**	**	NS	NS	**	**	NS
	Q**	L*	NL	Q**	C**	C*	NL	NL	NL	L**	NL
Year											
2006	1.00a[b]	34.1a	89.7a	0.33a	137.3a	1,031.8a	180.5a	101.2a	127.7a	721.0a	6.1b
2007	0.98a	1.3b	3.8b	0.41a	28.3b	223.0b	46.8b	23.6b	13.6b	18.3b	7.6a
Cultivar											
Candy	0.95a	24.8a	9.3b	0.35a	15.5b	679.9a	120.6a	62.4a	77.9a	175.2b	7.2a
Texas Grano 1015 Y	1.00a	13.2b	84.8a	0.37a	148.6a	625.6a	114.9a	66.8a	70.5b	581.6a	6.5b
Percent breakover											
10	0.85d	4.04d	54.7b	0.31c	24.6a	694.6a	114.4ab	62.6b	72.0b	828.6a	6.6a
20	1.10ab	15.68c	9.4c	0.40ab	16.9a	685.6a	135.6a	79.9a	93.7a	592.8a	6.5a
30	1.03bc	1.06d	4.8d	0.37b	24.0a	447.8b	107.5b	59.0b	41.8c	120.6b	6.9a
40	1.16a	23.99b	261.3a	0.41a	15.8b	670.0a	104.3b	64.3b	93.5a	239.6b	7.1a
50	0.94cd	50.50a	12.1c	0.35bc	21.4b	776.3a	121.8ab	61.3b	83.7a	145.3b	7.1a

NS, non-significant; or significant at * $P \leq 0.05$ or ** $P \leq 0.01$ (ANOVA); there were no significant interactions; values were either not distributed in a linear manner (NL), or values were distributed in a linear (L) or quadratic (Q) manner.
[a] TKN, nitrogen in a Kjeldahl digest; TKP, phosphorus in a Kjeldahl digest.
[b] Values in a column followed by the same letter are not significantly different ($P \leq 0.05$, Ryan–Einot–Gabriel–Welsch multiple *F*-test).

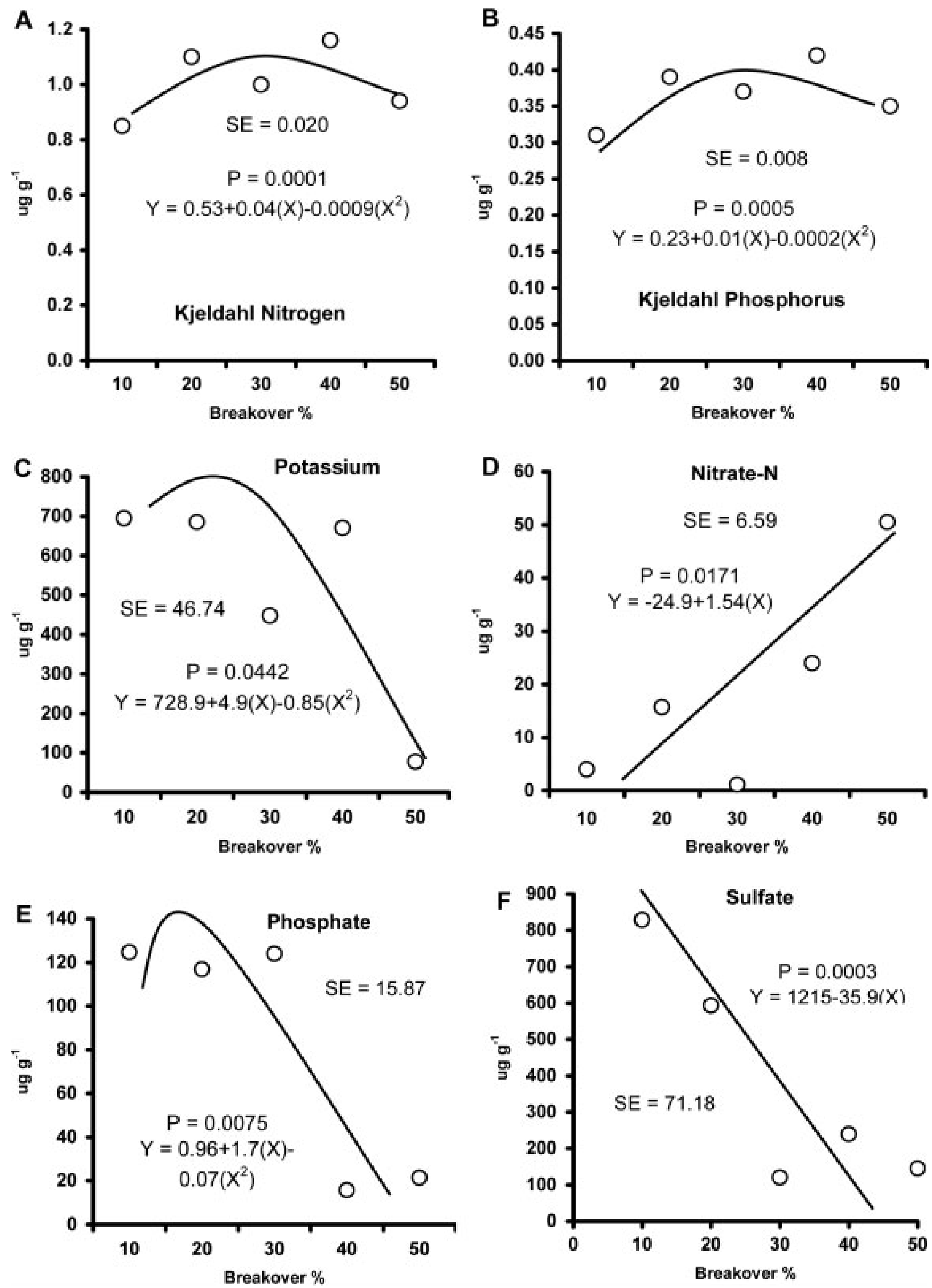

Figure 1. Distribution of chemical moieties that fit a linear distribution over cultivars, year and top condition at sampling times. Values for chemical moieties: increased and decreased over a small range ($\mu g\, g^{-1}$) as breakover increased (A, B); decreased as percent breakover increased (C, E, F); or increased as breakover increased (D).

of breakover, rather than time in the field, could be a visual marker of time to harvest so that nutrient content of bulbs is maximized. Year was important in how plant development and nutrient content were affected. During the 2 years precipitation amounts were different, with that in 2006 being nearer to normal. It was found that marketable production was increased under more frequent irrigation.[13] However, Shock *et al.*[13] conducted their work under normal growing conditions for the location. The relatively more normal, drier conditions in Oklahoma appeared to be more conducive to plant development and deposition of most nutrients in bulbs. Higher precipitation rates seem to be associated with increasing total soluble solids content. Higher available water did not appear to dilute total soluble solids. It may be that the higher concentrations of soluble solids may be due to plant responses to stress associated with the unusual amounts of water in the soil present during bulb development. Russo[2] determined that bulb size of these cultivars did not change much over time after breakover began. That observation was supported by similar findings in this study.

It appears that in some locations, and for some cultivars, it may not be necessary to harvest bulbs when the majority of tops have broken over. However, it will be necessary to confirm the results described here for different densities, locations and varying annual environmental conditions. For the conditions described it appears that about 20% top breakover can be a visual marker for harvest to maximize nutritive contents in bulbs.

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